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CONDUCTIVE GRIDS VS INTIMATE BLENDS WITH CONDUCTIVE FIBERS AS ALTERNATIVES TO TOPICAL ANTISTATIC TREATMENTS

By
Michelle Sutphin

April 1992

Final Report
October 1989 - July 1991

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Soldiers come into contact with volatile fuels, sensitive munitions, and other explosive substances, thus the risk of explosion due to electrostatic discharge is of great concern. This risk has increased now that more synthetic fibers are used in the soldiers' clothing and individual equipment. To reduce this risk, Natick includes static protection as an integral part of clothing worn in electrostatic sensitive environments. This is accomplished through the use of topical antistatic treatments. These finishes are non permanent, and require periodic retreatment of the uniform. Durable methods of static protection are under investigation, as reported here. Care must be taken to maintain other necessary fabric characteristics such as fabric durability, air permeability, flame resistance and camouflage properties. Promising methods for reducing charge buildup are the use of conductive fibers in the form of intimate blends or conductive grids.

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PREFACE

Soldiers come into contact with volatile fuels, sensitive munitions, and other explosive substances, thus the risk of explosion due to electrostatic discharge is of great concern. This risk has increased now that more synthetic fibers are used in the soldiers' clothing and individual equipment. To reduce this risk, Natick includes static protection as an integral part of clothing worn in electrostatic sensitive environments. This is accomplished through the use of topical antistatic treatments. These finishes are nonpermanent, and require periodic retreatment of the uniform. Durable methods of static protection are under investigation, as reported here. Care must be taken to maintain other necessary fabric characteristics such as fabric durability, air permeability, flame resistance and camouflage properties. Promising methods for reducing charge buildup are the use of conductive fibers in the form of intimate blends or conductive grids. This report is the result of work performed during the period from Oct 89 to Jul 91.

ACKNOWLEDGMENTS

Judy Sewell and Rita Devarakonda are recognized for their time spent laundering fabrics used for testing purposes. Raymond Markey is recognized for his expertise in the field of Textile Technology, having identified several unknown weave types, and an unknown substrate, as well as providing helpful comments during the writing of this report. Richard Cowan is also acknowledged for supplying useful comments and for originating the request for an X-Ray analysis of fabrics containing stainless steel. Peggy Goode is noted for performing and reporting on the X-Ray analysis of fabrics containing stainless steel. Lastly, Therese Commerford and Maurice Larrivee are recognized for their helpful suggestions and continual support. All of the above personnel are members of the Individual Protection Directorate.

Conductive Grids vs Intimate Blends with Conductive Fibers as Alternatives to Topical Antistatic Treatments

Introduction

With the increased use of synthetic materials in military uniforms, there exists a greater potential for electrostatic charge accumulation on clothing. This potential can be extremely hazardous when present in the wrong environment. Personnel handling fuel, munitions, and other electrostatic sensitive substances, are at risk. The hazard multiplies with increased charge accumulation, the use of nonconductive clothing, the inability to ground oneself, and with lower humidities and cooler temperatures.

In the past, topical antistatic treatments were used to decrease charge accumulation on textile materials for wear in electrostatic sensitive areas. It is known, however, that these treatments are not durable, and remain effective for a limited number of launderings. Additionally, topical antistats decrease or counteract the performance of other topical treatments, such as flame-retardants and water-repellants. For this reason, a more durable solution to the control of charge accumulation, without adversely affecting other desirable material properties, was sought. This began with the addition of stainless steel fibers to the fabric blend and expanded to the addition of fibers with conductive coatings and conductive cores and the use of various types of conductive materials. Nickel, carbon, and silver are only a few of the conductive materials which may be utilized in electrostatic protective materials. These materials may be integrated in the form of intimate blends, conductive grids, conductive filaments/yarns, and as coatings of the fabric surface.

Since survival, protection and comfort are key features which must be achieved, various material characteristics need to be considered when evaluating potential solutions to the static problem. Properties of interest include visual and near infrared characteristics for effective camouflage as well as fabric durability, air permeability, flame resistance, etc. Therefore, metal-coated fabrics can be immediately eliminated as a method of static control, for obvious camouflage reasons. Small percentages of metal and carbon fibers/filaments, in blend or grid form, can be added without significant change to visual characteristics. These are the fibers and fabric constructions being considered as a replacement for topical antistats.

Background

Fabric blends with conductive fibers, as well as fabrics containing conductive grids, have been investigated as alternatives to topical antistats. Various percentages, types, and methods of integrating the conductive fiber into the fabric have been examined. The test results of these materials have been analyzed to determine whether or not there is an advantage to using conductive grids, as opposed to conductive fibers in an intimate blend form.

Test Method and Equipment

All samples were tested according to Method 5931, "Electrostatic Decay Of Fabrics: Determination Of," Federal Test Method Standard 191A (see Appendix B). This test method measures how quickly fabric samples dissipate a charge. Each sample is charged toward 5000 volts for a period of 20 seconds, then grounded. The maximum voltage level (Vmax) obtained during this charging period is recorded. Decay time is measured by taking the difference in time from the instant the sample is grounded to the time the sample has dissipated 90% of its charge. Test results which yield Vmax values in excess of 4000 volts, and Decay Times of less than 0.5 second, are considered acceptable. Materials with these characteristics dissipate charge quickly, and exhibit low residual charge levels. Low levels of charge decrease the threat of electrostatic discharge in sensitive environments. Laundered samples are laundered according to Test Method 5556, Federal Test Method Standard 191A.

The following test equipment was used for the static measurements:

Model 406C Static Decay Meter by Electro-Tech Systems
(measures voltage levels and decay time of samples)
Model MPM 500 Thermo Hygro Tachometer by Solomat Corporation
(measures humidity)
Model 506 Humidity Test Chamber by Electro-Tech Systems
(maintains desired humidity levels for testing purposes)
Model SE-561 Memory Chart Recorder by BBC-Metrowatt/Goerz (BBC)
(plots decay curve)
Model M-2050 Digital Scope Multimeter by BBC
(used in place of analog meter on 406C for calibration purposes)

Due to electrical failure of the Model 406C Static Decay Meter, some of the samples were tested on similar equipment belonging to the Navy:

Model 406C Static Decay Meter by Electro-Tech Systems
Model 512 Automatic Humidity Controller by Electro-Tech Systems
Model 512-HS Humidity Sensor
Model 506 Humidity Test Chamber

Test Materials

See Table 1, Appendix A (from references 1 and 2). Six materials with conductive grids, 14 materials consisting of conductive fibers in an intimate blend form (7 blends with stainless steel and 7 blends with carbon fibers), as well as two materials with neither conductive fiber nor antistatic finish, are reported herein. Samples were tested both before and after laundering, according to Test Method 5931 of Federal Test Method Standard 191A. Laundered samples were laundered according to Test Method 5556 of the same Standard.

Results and Discussion

Results are recorded in Table 2, Appendix A. The two materials without static protection performed poorly, accepting less than 1000 volts when charged toward 5000 volts. The first of these two materials is 100% polyester, which is the base material for the samples containing conductive grids. The second of the two materials is a Nomex/Kevlar blend which had previously been treated with an antistatic finish, though the finish was removed in laundering. The results of these two nonconductive blends can be used as a comparison to those materials reported which contain conductive fibers/filaments.

Of the conductive materials tested, the fabrics containing carbon appear to be the least affected by laundering and, thus, the most stable (see Figures A-1, A-2 and A-6). These blends perform well electrostatically, provided enough carbon is present in the material. Figure A-3, which displays the averaged results of the Aramid/Carbon blends given in Table 2, indicates that at least 3.6 percent carbon is needed to meet the Vmax $\geq$ 4000 volts after five launderings. Stainless steel blends require at least 4.4 percent conductive fiber to achieve these results after 5 launderings (see Figure A-4). The stainless steel blends were also affected more by laundering. With the exception of the 10 percent stainless steel sample, all of the samples tested either failed to meet the 4000 volt minimum Vmax level in the warp and/or filling direction or exhibited decay times greater than 1/2 second (see Table 2 and Figure A-5) after 5 launderings. The sample containing 10 percent stainless steel was able to achieve an average Vmax level of 4192 volts after being laundered only 5 times, compared to the 4 percent BCC (Bi-Component Carbon) needed to reach the same level after having been laundered 50 times (refer Table 2). Additionally, previous X-Ray analysis of materials containing stainless steel indicate that surface migration and clustering of the stainless steel fibers occurs after laundering (3), possibly a result of the stainless steel fiber being much heavier in weight than the aramid fibers (stainless steel has a density of 7.8 [grams]/[cubic centimeter] [g/cm^3] [4] while the densities of Nomex and of Kevlar are 1.38 g/cm^3 and 1.44 to 1.47 g/cm^3, respectively, [5]) in the fabric. The difference in Vmax levels after laundering may also be attributed to the removal of humectants, which are often added for a better "hand."

Figure A-6, which illustrates the effect of laundering on conductive grids, shows that the sample most affected by laundering was that with an incomplete grid; a conductive monofilament (silver coated nylon) running in the filling direction only, at 1/2-inch spacing. The grid second most affected was that of the 1/2 inch silver-coated nylon complete grid. It is believed the positive results on these fabrics prior to laundering are due to the presence of humectants, and that a 1/4-inch grid, as opposed to a 1/2-inch grid, using silver coated nylon would yield significantly better results after laundering. Due to the lack of data, metallic grids cannot be ruled out as an effective method of controlling static. The three 1/4 inch grids tested met the 4000 volt Vmax level both before and after laundering, though two performed better than the third, and were more stable after laundering. The 1/4 inch grid materials with better performance probably utilize a more conductive carbon yarn. The 1/8 inch grid tested, which was expected to perform the best of all grids, did not

perform as expected, possibly due to a less conductive carbon yarn. Note the stability of the results after repeated launderings (see Figure 6). Since the data on the conductive grids is limited, optimum grid size cannot be determined without further sample testing.

The decay times of all fabrics met the $\leq$ 0.5 second requirement, with the exception of the following:

a.) polyester with silver-coated nylon filaments spaced 1/2 inch apart in filling direction only, which exhibited very high decay times after laundering (an average of greater than 13 seconds)

b.) 98 percent Nomex/Kevlar, 2 percent Stainless Steel, Oxford Weave, which had an average decay time of 0.73 seconds in the filling direction prior to laundering, and had an overall average decay time of 3.95 seconds after laundering.

c.) 98 percent Nomex, 2 percent P140 (Olive Green), which exhibited an average decay time of 0.734 seconds prior to laundering

d.) Aramid blend, carbonized, which revealed an average decay time of 3.3 seconds prior to laundering and 0.7 second after laundering.

Conclusion: It is concluded that both conductive blends and conductive grids are acceptable methods of controlling static in otherwise static-prone fabrics through the use of proper grid sizes and proper blend levels. The present results indicate a grid size of 1/4 inch is appropriate when using a conductive carbon grid to obtain desirable electrostatic properties after laundering. Further testing must be conducted to determine whether this also holds true for metallic grids, such as silver-coated nylon. It is expected a decrease in grid size from 1/2- to 1/4-inch would improve the performance of materials containing a silver-coated nylon grid to an acceptable level. Results for intimate blends with conductive carbon fibers indicate at least 3.6 percent conductive carbon fiber is needed to obtain good electrostatic properties after laundering. A level of at least 4.4 percent is required for stainless steel. These percentages are based on Figures A-3 and A-4, which utilize "best fit" curves. Intimate blends containing stainless steel were found to be affected more by laundering than the carbon grids and the carbon blends (with the exception of the "carbonized" fabric). Stainless steel fibers appear to migrate together when laundered, possibly due to their heavier weight as compared to other fibers, resulting in a decrease in static performance. The presence of humectants on the stainless steel blends prior to laundering may also be a contributing factor. The silver-coated nylon grids were also significantly affected by laundering, probably due to the presence of humectants prior to laundering. Note that several of the carbon blend fabrics were laundered 50 times with little change in electrostatic properties.

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Appendix A

TABLES AND FIGURES

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Table 1 Sample Descriptions

1. Materials with no conductive fiber and no topical antistatic treatment.

   a. 100 percent Polyester, Barrier Fabric 402482, Plain Weave, Klopman Fabrics, Blue A195

   b. 100 percent Nomex/Kevlar, Plain Weave, Isomex Industries, DAAK60-85-C-0013, MIL-C-83429, roll #19373, A-1 Tube 356, Camouflage Print

2. Materials with Conductive Grids

   a. 99 percent Textured Polyester Filament Yarn, 1 percent Carbon suffused nylon filament yarn in diamond shaped grid form (approximately 1/4-inch in size), warp knit, Red Kap Industries, blue

   b. Polylock 401175, 100 percent Polyester filament yarn with carbon grid (approximately 1/4-inch in size), plain weave, Klopman Fabrics Division of Burlington Industries, Durapel Finish, Blue M481

   c. 100 percent Polyester filament yarn with carbon grid (approximately 1/8-inch in size), twill, Klopman Fabrics Division of Burlington Industries, white

   d. 100 percent Polyester filament yarn with silver coated nylon filament yarn in 1/2-inch grid form, plain weave, Sauquoit Industries, white

   e. 100 percent Polyester filament yarn with silver coated nylon filament yarn in filling direction only (1/2-inch spacing), plain weave, Sauquoit Industries, white

   f. 100 percent Polyester with carbon core grid (approximately 1/4-inch in size), plain weave, AG-III no. 6306 (EW769W), Kanebo, Ltd., Osaka, Japan, Red

3. Materials Containing Conductive Fibers (Intimate Blends)

   a. Stainless Steel Fibers

      (1) 99 percent 95/5 Nomex/Kevlar, 1 percent Stainless Steel, Burlington Plain Weave, MIL-C-83429, DAAK60-87-C-0004, Woodland Printed

      (2) 99 percent 95/5 Nomex/Kevlar, 1 percent Stainless Steel, Burlington Oxford Weave, MIL-C-83429, DAAK60-87-C-0004, Woodland Printed

Table 1 Sample Descriptions (cont'd)

(3) 99 percent 95/5 Nomex/Kevlar, 1 percent Stainless Steel, Plain Weave, Professional Chemical & Color, MIL-C-83429, DAAK60-88-C-0064, Woodland Printed

(4) 99 percent 95/5 Nomex/Kevlar, 1 percent Stainless Steel, Oxford Weave, Professional Chemical & Color, MIL-C-83429, DAAK60-88-C-0064, Woodland Printed

(5) 98 percent 95/5 Nomex/Kevlar, 2 percent Stainless Steel, Wickwell Finish, Plain Weave, Springs Industries/Prochroma, DAAK60-90-C-0062, MIL-C-83429, Aircrew BDU, Woodland Printed,

(6) 98 percent 95/5 Nomex/Kevlar, 2 percent Stainless Steel, Wickwell Finish, Oxford Weave, Springs Industries/Prochroma, DAAK60-90-C-0062, MIL-C-83429, Aircrew BDU, Woodland Printed,

(7) 90 percent Nomex, 10 percent Stainless Steel, Plain Weave, Greige fabric (source unknown)

b. Carbon Fibers

(1) 99 percent T455 Nomex/Kevlar, 1 percent BCC (Bi-Component Carbon), Plain Weave, DAAK60-81-C-0152, Dark Green

(2) 98 percent T456 Nomex Aramid Staple, 2 percent P140, Plain Weave, DuPont, MIL-C-83429, Green

(3) 98 percent 95 Nomex, 2 percent P140, Plain Weave, DuPont, MIL-C-83429, Olive Green

(4) 98 percent 95/5 Nomex/Kevlar, 2 percent P140, Plain Weave, Southern Mills/ DuPont, DAAK60-90-C-0046, MIL-C-83429, Aircrew BDU, Woodland Printed

(5) 96 percent T455 Nomex/Kevlar, 4 percent BCC (Bi-Component Carbon), Plain Weave, DAAK60-81-C-0152, Dark Green

(6) 93 percent T455 Nomex/Kevlar, 7 percent BCC (Bi-Component Carbon), Plain Weave, DAAK60-81-C-0152, Dark Green

(7) Aramid Blend, Carbonized, Amatex Corp., Aircrew BDU, VEE 6311, Camouflage print,

Table 2 Electrostatic Properties

1. Materials with no conductive fiber and no topical antistatic treatment.

a. 100 percent Polyester:

	Average Vmax (Volts)	Average Decay Time (Seconds)
Antistat Initial:		
Average Warp	958	$
Average Filling	758	$
Overall Average	858	$

b. 100 percent Nomex/Kevlar:

	Average Vmax (Volts)	Average Decay Time (Seconds)
Antistat Initial:		
Average Warp	467	$
Average Filling	392	$
Overall Average	429	$

2. Materials with Conductive Grids

a. Polyester with 1/4" carbon suffused nylon grid (Red Kap):

	Average Vmax (Volts)	Average Decay Time (Seconds)
Antistat Initial:		
Average Warp	5000	0.01
Average Filling	5000	0.01
Overall Average	5000	0.01
Laundered 5x (TM 5556)		
Average Warp	4875	0.01
Average Filling	4500	0.01
Overall Average	4688	0.01

b. Polyester with 1/4" carbon grid, blue (Klopman):

	Average Vmax (Volts)	Average Decay Time (Seconds)
Antistat Initial:		
Average Warp	4604	0.01
Average Filling	4667	0.01
Overall Average	4635	0.01

$ Unable to measure decay time due to low voltage levels.

Table 2 Electrostatic Properties (cont'd)

b. Polyester with 1/4" carbon grid, blue (Klopman) (cont.):

	Average Vmax (Volts)	Average Decay Time (Seconds)
Laundered 5x (TM 5556)		
Average Warp	4188	0.01
Average Filling	4063	0.01
Overall Average	4125	0.01

c. Polyester with 1/8" carbon grid, white (Klopman):

	Average Vmax (Volts)	Average Decay Time (Seconds)
Antistat Initial:		
Average Warp	3729	0.01
Average Filling	3625	0.01
Overall Average	3677	0.01
Laundered 5x (TM 5556)		
Average Warp	3542	0.01
Average Filling	3625	0.01
Overall Average	3583	0.01

d. Polyester with 1/2" silver coated nylon grid (Sauquoit):

	Average Vmax (Volts)	Average Decay Time (Seconds)
Antistat Initial:		
Average Warp	5000	0.01
Average Filling	5000	0.01
Overall Average	5000	0.01

	Average Vmax (Volts)	Average Decay Time (Seconds)
Laundered 5x (TM 5556)		
Average Warp	3583	0.01
Average Filling	3854	0.01
Overall Average	3719	0.01

e. Polyester with 1/2" silver-coated nylon in filling direction only (Sauquoit):

(Volts)	Average Vmax (Seconds)	Average Decay Time
Antistat Initial:		
Average Warp	5000	0.59
Average Filling	5000	0.02
Overall Average	5000	0.30

Table 2 Electrostatic Properties (cont'd)

e. Polyester with 1/2" silver-coated nylon in filling direction only (Sauquoit) (cont.):

	Average Vmax (Volts)	Average Decay Time (Seconds)
Laundered 5x (TM 5556)		
Average Warp	1042	>20.00
Average Filling	4042	>10.01
Overall Average	2542	>13.34

f. Polyester with 1/4" carbon core grid (Kanebo):

	Average Vmax (Volts)	Average Decay Time (Seconds)
Antistat Initial:		
Average Warp	4958	0.01
Average Filling	4875	0.01
Overall Average	4917	0.01
Laundered 5x (TM 5556)		
Average Warp	4833	0.01
Average Filling	4583	0.01
Overall Average	4708	0.01

3. Materials Containing Conductive Fibers (Intimate Blends)

a. Stainless Steel Fibers

(1) 99 percent Nomex/Kevlar, 1 percent Stainless Steel (DAAK60-87-C-0004), Plain Weave:

	Average Vmax (Volts)	Average Decay Time (Seconds)
Antistat Initial:		
Average Warp	4383	0.010
Average Filling	4600	0.006
Overall Average	4492	0.008
Laundered 5x (TM 5556)		
Average Warp	3717	0.003
Average Filling	4075	0.004
Overall Average	3896	0.003

Table 2 Electrostatic Properties (cont'd)

(2) 99 percent Nomex/Kevlar, 1 percent Stainless Steel (DAAK60-87-C-0004), Oxford Weave:

	Average Vmax (Volts)	Average Decay Time (Seconds)
Antistat Initial:		
Average Warp	4608	0.004
Average Filling	4367	0.005
Overall Average	4488	0.004
Laundered 5x (TM 5556)		
Average Warp	4158	0.002
Average Filling	3767	0.002
Overall Average	3963	0.002

(3) 99 percent Nomex/Kevlar, 1 percent Stainless Steel (DAAK60-88-C-0064), Plain Weave:

	Average Vmax (Volts)	Average Decay Time (Seconds)
Antistat Initial:		
Average Warp	4900	0.195
Average Filling	4917	0.303
Overall Average	4909	0.249
Laundered 5x (TM 5556)		
Average Warp	2625	0.003
Average Filling	2450	0.003
Overall Average	2538	0.003

(4) 99 percent Nomex/Kevlar, 1 percent Stainless Steel (DAAK60-88-C-0064), Oxford Weave:

	Average Vmax (Volts)	Average Decay Time (Seconds)
Antistat Initial:		
Average Warp	4875	0.004
Average Filling	5050	0.257
Overall Average	4963	0.131
Laundered 5x (TM 5556)		
Average Warp	4042	0.002
Average Filling	1067	*
Overall Average	2554	*

* Decay time not measured for these samples.

Table 2 Electrostatic Properties (cont'd)

(5) 98 percent Nomex/Kevlar, 2 percent Stainless Steel, Plain Weave:

	Average Vmax (Volts)	Average Decay Time (Seconds)
Antistat Initial:		
Average Warp	5000	0.01
Average Filling	5000	0.24
Overall Average	5000	0.13
Laundered 5x (TM 5556)		
Average Warp	4125	0.01
Average Filling	3958	0.01
Overall Average	4042	0.01

(6) 98 percent Nomex/Kevlar, 2 percent Stainless Steel, Oxford Weave:

	Average Vmax (Volts)	Average Decay Time (Seconds)
Antistat Initial:		
Average Warp	4708	0.01
Average Filling	4417	0.73
Overall Average	4563	0.37
Laundered 5x (TM 5556)		
Average Warp	4396	0.01
Average Filling	4146	7.89
Overall Average	4271	3.95

(7) 90 percent Nomex/Kevlar, 10 percent Stainless Steel:

	Average Vmax (Volts)	Average Decay Time (Seconds)
Antistat Initial:		
Average Warp	4450	0.002
Average Filling	4333	0.002
Overall Average	4392	0.002
Laundered 5x (TM 5556)		
Average Warp	4283	0.002
Average Filling	4100	0.002
Overall Average	4192	0.002

Table 2 Electrostatic Properties (cont'd)

b. Carbon Fibers

(1) 99 percent T455 Nomex/Kevlar, 1 percent BCC:

	Average Vmax (Volts)	Average Decay Time (Seconds)
Antistat Initial:		
Average Warp	3177	*
Average Filling	3550	*
Overall Average	3333	*
Laundered 50x (TM 5556)		
Average Warp	3108	*
Average Filling	2950	*
Overall Average	3029	*

(2) 98 percent Nomex/Kevlar, 2 percent P140, Green:

	Average Vmax (Volts)	Average Decay Time (Seconds)
Antistat Initial:		
Average Warp	3725	0.003
Average Filling	3275	0.003
Overall Average	3500	0.003
Laundered 5x (TM 5556)		
Average Warp	3583	0.004
Average Filling	3408	0.003
Overall Average	3496	0.003

(3) 98 percent Nomex, 2 percent P140, Olive Green:

	Average Vmax (Volts)	Average Decay Time (Seconds)
Antistat Initial:		
Average Warp	4708	0.810
Average Filling	4600	0.658
Overall Average	4654	0.734
Laundered 5x (TM 5556)		
Average Warp	3725	0.332
Average Filling	3542	0.008
Overall Average	3633	0.170

* Decay time not measured for these samples.

Table 2 (cont.) Electrostatic Properties (cont'd)

(4) 98 percent Nomex/Kevlar, 2 percent P140, Woodland Print:

	Average Vmax (Volts)	Average Decay Time (Seconds)
Antistat Initial:		
Average Warp	4042	0.01
Average Filling	4250	0.07
Overall Average	4146	0.04
Laundered 5x (TM 5556)		
Average Warp	3625	0.01
Average Filling	3333	0.01
Overall Average	3479	0.01

(5) 96 percent T455 Nomex/Kevlar, 4 percent BCC:

	Average Vmax (Volts)	Average Decay Time (Seconds)
Antistat Initial:		
Average Warp	4175	0.003
Average Filling	4125	0.002
Overall Average	4150	0.003
Laundered 50x (TM 5556)		
Average Warp	4200	0.003
Average Filling	4183	0.003
Overall Average	4192	0.003

(6) 93 percent T455 Nomex/Kevlar, 7 percent BCC:

	Average Vmax (Volts)	Average Decay Time (Seconds)
Antistat Initial:		
Average Warp	4375	0.003
Average Filling	4392	0.003
Overall Average	4383	0.003
Laundered 50x (TM 5556)		
Average Warp	4392	0.003
Average Filling	4325	0.003
Overall Average	4358	0.003

Table 2 (cont.)

Electrostatic Properties

(7) Aramid blend, carbonized:

	Average Vmax (Volts)	Average Decay Time (Seconds)
Antistat Initial:		
Average Warp	4642	3.1
Average Filling	4733	3.6
Overall Average	4688	3.3
Laundered 5x (TM 5556)		
Average Warp	4718	0.5
Average Filling	4783	0.9
Overall Average	4751	0.7

Figure A-1 Comparison: Grids and Blends
Effect of Laundering

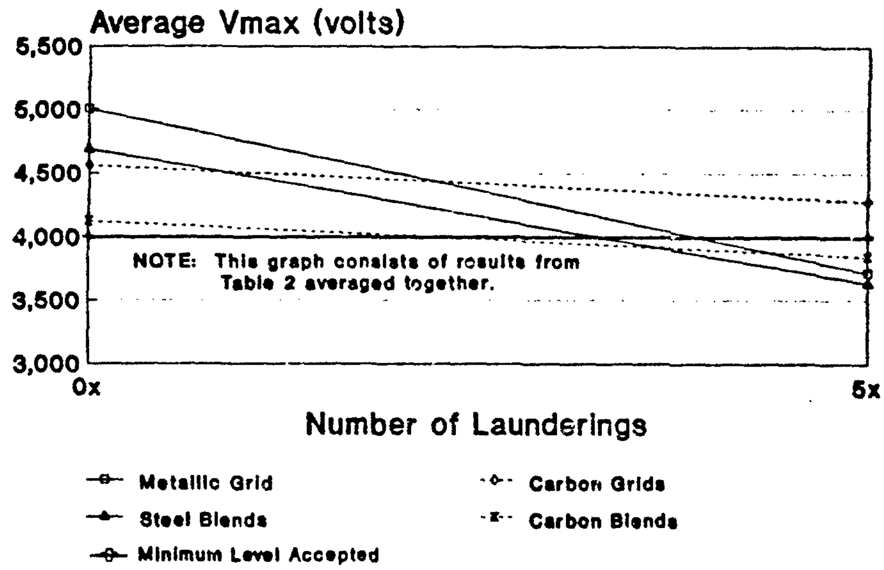


Figure A-2 Carbon Blends
Effect of Laundering

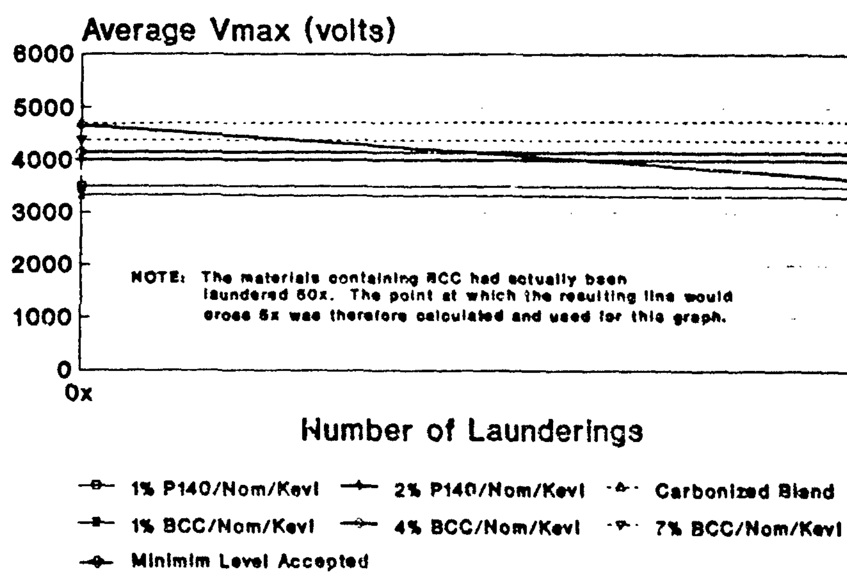


Figure A-3 Carbon Blends
Effect of % Carbon Fiber

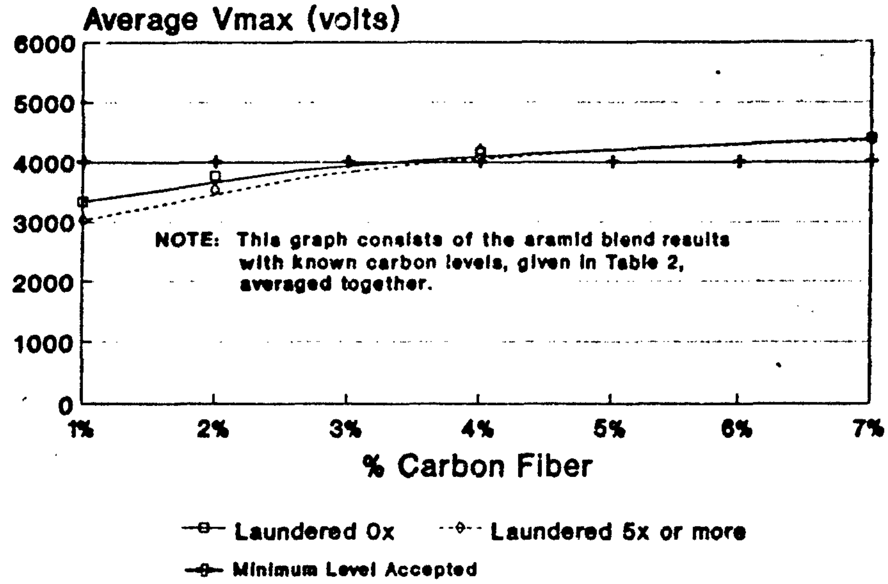


Figure A-4 Stainless Steel Blends
Effect of % Stainless Steel

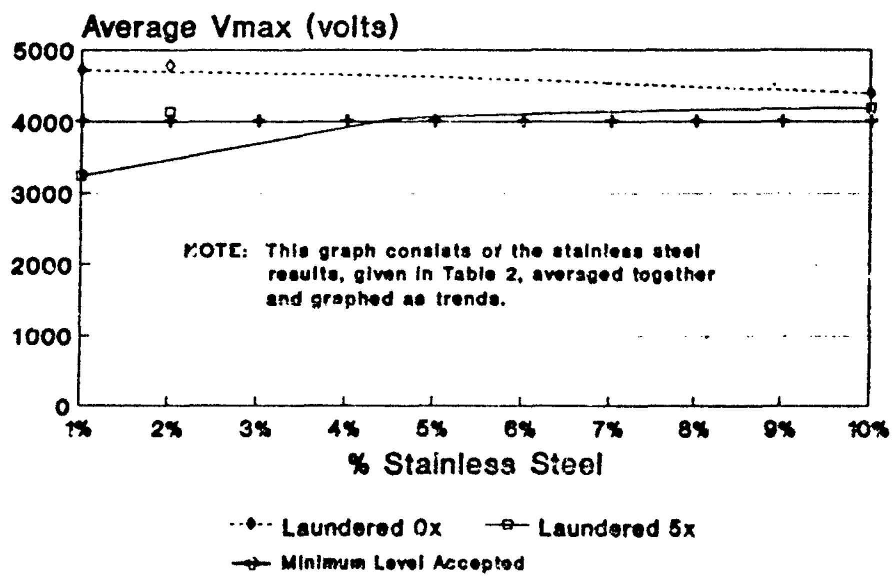
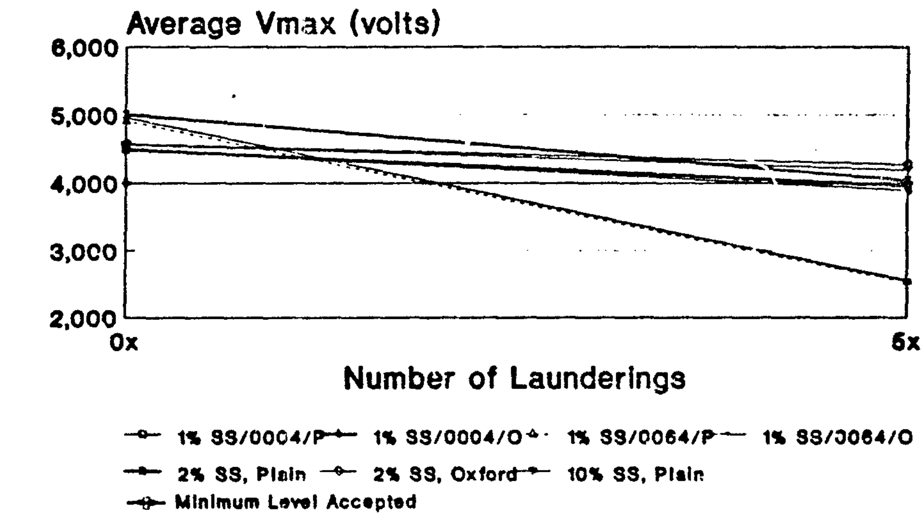
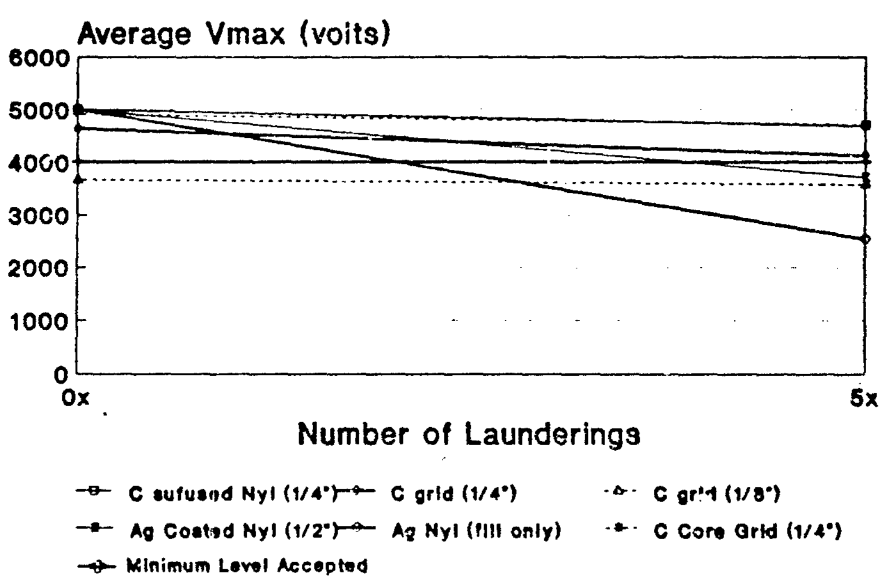


Figure A-5 Stainless Steel Blends
Effect of Laundering



Note: "P" represents "Plain Weave"
"O" represents "Oxford Weave"
0004 & 0064 Identify Contract No.

Figure A-6 Conductive Grids
Effect Of Laundering



Appendix B

TEST METHOD 5931

ELECTROSTATIC DECAY OF FABRICS;

DETERMINATION OF

1. SCOPE

1.1 This method is intended for determining the time it takes for a charge on a fabric surface to decay to an electrostatically safe level. This method is appropriate for use on material which may or may not contain conductive fibers, or have been treated with an antistat finish. The ultimate purpose is to determine which materials are safe for wear during electrostatic sensitive operations.

2. TEST SPECIMEN

2.1 The specimen shall be a 3- by 5-inch rectangular piece of material. The warp or filling yarns shall run parallel to the 5-inch length of the specimen. The direction of test (warp or filling) shall be along the length of the specimen and each specimen shall be labeled accordingly in one corner. Test specimens shall be cut so that no two contain the same set of warp and filling yarns.

3. NUMBER OF DETERMINATIONS

3.1 Unless otherwise specified in the procurement document, six specimens shall be tested, three in the warp direction and three in the filling direction.

4. APPARATUS

4.1 The apparatus shall consist of a humidity test chamber, a meter for measuring relative humidity (RH) and temperature, a faraday cage, a source capable of outputing 5000 volts, and a recorder on which voltage behavior with respect to time may be plotted. The faraday cage shall contain two parallel electrodes, on which specimens may be mounted and charged, and a sensor by which voltage on the specimen surface may be detected. The apparatus shall also include voltage meters to display the applied voltage, and the voltage detected by the sensor.

5. PROCEDURE

5.1 The faraday cage and specimens to be tested shall be preconditioned at 10 $\pm$ 2 percent relative humidity overnight, and conditioned at 20 $\pm$2 percent relative humidity for a minimum of 24 hours at approximately 75 $\pm$ 5°F. The specimens shall be tested at 20 $\pm$ 2 percent relative humidity and 75 $\pm$ 5°F. An air-ionizing blower can be used within the chamber while conditioning, although the blower must be turned off once testing begins.

5.2 Allow test equipment 1 hour of warm-up time. Adjust voltage source for a charging voltage of 5000 volts. Mount a 3- by 5-inch aluminum plate across the electrodes in the faraday cage, such that it is centered in front of the voltage sensor opening. Apply a charge of 5000 volts, and calibrate the voltage meter designated to indicate detected voltage on the sample equal to 5000 volts. Remove the aluminum plate.

5.3 Mount a specimen tautly across the electrodes, centering it over the sensor opening. The surface of test specimen (back or front) shall face the sensor. A deionizing bar may be used on the specimen before the test to remove residual charge. Apply 5000 volts to the electrodes for a period of 20 seconds. At the end of the 20-second period, the high voltage (5000 volts) shall be turned off and the specimen immediately grounded. The voltage behavior of the specimen with respect to time shall be plotted on the recorder.

5.4 The maximum voltage level reached on the specimen shall be measured from the recorder curve as the difference between the highest level and lowest level of the full decay curve. If the specimen did not reach a maximum voltage of at least 4000 volts during the 20-second charging period, the specimen shall be recorded as non-passing and the reason noted. The time for the charge to decay from the maximum voltage level to 10 percent of the maximum level shall be measured from the voltage plot.

5.5 The specimen is acceptable if the decay time to 10 percent of the maximum voltage is less than 1/2 second, and considered not acceptable otherwise. Record the maximum voltage level and decay time to 10 percent. The reason for any failures shall be noted.

5.6 Remove specimen. Repeat 5.3 through 5.5 for the front and back sides of each specimen of the test fabric.

5.7 Recalibrate periodically, at the minimum between each set of six specimens.

6. REPORT

6.1 The test method used, and any alterations to the method, shall be reported.

6.2 Test conditions, including relative humidity, room temperature, and conditioning time shall be stated.

6.3 Equipment names, model numbers, and manufacturers shall be listed. Special modifications to equipment shall be described. A description of any equipment built in-house shall be included.

6.4 Identification of materials tested, including name, composition, weave, printed/dyed, finishes, manufacturer and any other pertinent information shall be included.

6.5 Alterations to materials shall be noted together with the test method used, or description of the process applied; e.g., laundering.

6.6 The average time to decay to 10 percent of the maximum voltage shall be included for each of the warp and filling directions, as well as the overall average, for each fabric tested. It shall be indicated whether the fabric is acceptable, or non-acceptable.

7. NOTES

7.1 Equipment suitable for conducting this test may be purchased from:

Electro-Tech Systems, Inc. 115 E. Glenside Avenue Glenside, PA 19038	(Model 506 Controlled Humidity Test Chamber, Model 406C Static Decay Meter (includes faraday cage))
ABB Metrawatt, Inc. 2150 West 6th Avenue Bloomfield, CO 80020	(Model SE-561 Memory Chart Recorder)
Solomat Corporation Glenbrook Industrial Park 652 Glenbrook Road Stamford, CT 06906	(Model MPM 500 Thermo Hygro Tachometer)

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